

# Contents

---

<b>Chapter 1 • Introduction</b>	<b>1</b>
1.1    The History of Antennas	1
1.1.1    Overview of the History of Communications	1
1.1.2    The Significant Contributions to the Understanding of Electromagnetic Waves	3
1.1.3    Key Developments in Communication Technology	5
1.1.4    Long-Distance Wireless Communications	7
1.1.5    The Modern Era of Wireless	9
1.2    What Is an Antenna and When Is it Used?	10
1.2.1    What Is an Antenna?	10
1.2.2    When Is an Antenna Used?	12
1.3    How Antennas Radiate	13
1.4    The Four Antenna Types	17
References	22
Problems	22
<b>Chapter 2 • Antenna Fundamentals</b>	<b>23</b>
2.1    Fundamentals of Electromagnetics	23
2.2    Solution of Maxwell's Equations for Radiation Problems	27
2.3    The Ideal Dipole	32
2.4    Radiation Patterns	36
2.4.1    Radiation Pattern Basics	36
2.4.2    Radiation from Line Currents	37
2.4.3    Far-Field Conditions and Field Regions	40
2.4.4    Steps in the Evaluation of Radiation Fields	44
2.4.5    Radiation Pattern Definitions	46
2.4.6    Radiation Pattern Parameters	49
2.5    Directivity and Gain	50
2.6    Antenna Impedance	56
2.7    Radiation Efficiency	60
2.8    Antenna Polarization	61
References	66
Problems	66
<b>Chapter 3 • Simple Radiating Systems</b>	<b>70</b>
3.1    Electrically Small Dipoles	70
3.2    Half-Wave Dipoles	73
3.3    Monopoles and Image Theory	75
3.3.1    Image Theory	76
3.3.2    Monopoles	78
3.4    Small Loop Antennas and Duality	81
3.4.1    Duality	81
3.4.2    The Small Loop Antenna	84

3.5 Two-Element Arrays	89	6.7 Wire Antennas Above an Imperfect Ground Plane	198
References	97	6.7.1 Pattern Effects of a Real Earth Ground Plane	198
Problems	97	6.7.2 Ground Plane Construction	202
<b>Chapter 4 • System Applications for Antennas</b>	<b>100</b>	6.8 Large Loop Antennas	205
4.1 Introduction	100	References	211
4.2 Receiving Properties of Antennas	100	Problems	212
4.3 Antenna Noise and Radiometry	103		
4.4 Antennas in Communication Systems	107		
4.4.1 Directivity, Gain, and Effective Aperture	107		
4.4.2 Communication Links	109		
4.4.3 Effective Isotropically Radiated Power (EIRP)	110		
4.4.4 Impedance Mismatch	112		
4.4.5 Polarization Mismatch	113		
4.5 Antennas In Wireless Communication Systems	116		
4.5.1 Spatial Frequency Reuse and Cellular Systems	116		
4.5.2 Propagation Effects on Communication Links	119		
4.5.3 Gain Estimation	120		
4.6 Antennas in Radar Systems	122		
4.7 Antennas As Unintentional Radiators	123		
References	125		
Problems	125		
<b>Chapter 5 • Line Sources</b>	<b>128</b>		
5.1 The Uniform Line Source	128		
5.2 Tapered Line Sources	137		
5.3 Fourier Transform Relations Between the Far-Field Pattern and the Source Distribution	142		
5.4 Fast Wave And Slow Wave Distributions	143		
5.5 Superdirective Line Sources	145		
References	148		
Problems	148		
<b>Chapter 6 • Wire Antennas</b>	<b>151</b>		
6.1 Dipole Antennas	151		
6.1.1 Straight Wire Dipoles	152		
6.1.2 The Vee Dipole	160		
6.2 Folded Dipole Antennas	161		
6.3 Yagi-Uda Antennas	166		
6.4 Feeding Wire Antennas	175		
6.4.1 Transmission Lines	175		
6.4.2 Matching Networks	177		
6.4.3 Baluns	181		
6.5 Loaded Wire Antennas	186		
6.5.1 Lumped Loaded Wire Antennas	186		
6.5.2 Distributively Loaded Wire Antennas and Fractals	189		
6.6 Ground Plane Backed Wire Antennas	190		
6.6.1 The Flat Plate Reflector	190		
6.6.2 Corner Reflector Antennas	192		
6.6.3 Backfire Antennas	194		
<b>Chapter 7 • Broadband Antennas</b>	<b>218</b>		
7.1 Introduction	218		
7.2 Traveling-Wave Wire Antennas	220		
7.3 Helical Antennas	225		
7.3.1 Normal Mode Helix Antennas	226		
7.3.2 Axial Mode Helix Antennas	229		
7.4 Biconical Antennas	233		
7.4.1 The Infinite Biconical Antenna	233		
7.4.2 Finite Biconical Antennas	235		
7.4.3 Discone Antennas	236		
7.5 Sleeve Antennas	239		
7.5.1 Sleeve Monopoles	240		
7.5.2 Sleeve Dipoles	241		
7.6 Principles of Frequency-Independent Antennas	243		
7.7 Spiral Antennas	245		
7.7.1 Equiangular Spiral Antennas	246		
7.7.2 Archimedean Spiral Antennas	247		
7.7.3 Conical Equiangular Spiral Antennas	249		
7.7.4 Related Configurations	250		
7.8 Log-Periodic Antennas	251		
7.9 Wideband EMC Antennas	261		
7.10 Ultra-Wideband Antennas	264		
References	266		
Problems	268		
<b>Chapter 8 • Array Antennas</b>	<b>271</b>		
8.1 Introduction	271		
8.2 The Array Factor for Linear Arrays	272		
8.3 Uniformly Excited, Equally Spaced Linear Arrays	278		
8.3.1 The Array Factor Expression	278		
8.3.2 Main Beam Scanning and Beamwidth	282		
8.3.3 The Ordinary Endfire Array	283		
8.3.4 The Hansen-Woodyard Endfire Array	285		
8.4 The Complete Array Pattern and Pattern Multiplication	286		
8.5 Directivity of Uniformly Excited, Equally Spaced Linear Arrays	293		
8.6 Nonuniformly Excited, Equally Spaced Linear Arrays	298		
8.7 Mutual Coupling in Arrays	303		
8.7.1 Impedance Effects of Mutual Coupling	304		
8.7.2 Array Pattern Evaluation Including Mutual Coupling	308		
8.8 Multidimensional Arrays	311		
8.9 Phased Arrays and Array Feeding Techniques	314		
8.9.1 Scan Principles	315		
8.9.2 Feed Networks and Array Technology	320		
8.9.3 Operational Array Examples and the Future of Arrays	325		

8.10 Elements for Arrays	327	10.4 Low Side Lobe, Narrow Main Beam Synthesis Methods	446
8.11 Wideband Phased Arrays	332	10.4.1 The Dolph-Chebyshev Linear Array Method	447
References	336	10.4.2 The Taylor Line Source Method	453
Problems	338	10.5 The Iterative Sampling Method	459
<b>Chapter 9 • Aperture Antennas</b>	<b>344</b>	References	461
9.1 Radiation from Apertures and Huygens' Principle	344	Problems	461
9.2 Rectangular Apertures	353		
9.2.1 Uniform Rectangular Apertures	353		
9.2.2 Tapered Rectangular Apertures	357		
9.3 Techniques for Evaluating Gain	360		
9.3.1 Directivity	361		
9.3.2 Gain and Efficiencies	363		
9.3.3 Simple Directivity Formulas	365		
9.4 Rectangular Horn Antennas	368		
9.4.1 The <i>H</i> -Plane Sectoral Horn Antenna	369		
9.4.2 The <i>E</i> -Plane Sectoral Horn Antenna	375		
9.4.3 The Pyramidal Horn Antenna	379		
9.5 Circular Apertures	385		
9.5.1 The Uniform Circular Aperture	385		
9.5.2 Tapered Circular Apertures	388		
9.6 Reflector Antennas	391		
9.6.1 Parabolic Reflector Antenna Principles	391		
9.6.2 The Axisymmetric Parabolic Reflector Antenna	398		
9.6.3 Offset Parabolic Reflectors	402		
9.6.4 Dual Reflector Antennas	403		
9.6.5 Cross-Polarization and Scanning Properties of Reflector Antennas	407		
9.6.6 Gain Calculations for Reflector Antennas	410		
9.6.7 Other Reflector Antennas	415		
9.7 Feed Antennas for Reflectors	416		
9.7.1 Field Representations	416		
9.7.2 Matching the Feed to the Reflector	417		
9.7.3 A General Feed Model	419		
9.7.4 Feed Antennas Used in Practice	421		
9.8 Lens Antennas	424		
9.8.1 Dielectric Lens Antennas	424		
9.8.2 Constrained Lens Antennas	425		
References	425		
Problems	427		
<b>Chapter 10 • Antenna Synthesis</b>	<b>433</b>		
10.1 The Antenna Synthesis Problem	433		
10.1.1 Formulation of the Synthesis Problem	433		
10.1.2 Synthesis Principles	435		
10.2 Line Source Shaped Beam Synthesis Methods	437		
10.2.1 The Fourier Transform Method	437		
10.2.2 The Woodward-Lawson Sampling Method	438		
10.3 Linear Array Shaped Beam Synthesis Methods	440		
10.3.1 The Fourier Series Method	442		
10.3.2 The Woodward-Lawson Sampling Method	443		
10.3.3 Comparison of Shaped Beam Synthesis Methods	445		
<b>Chapter 11 • Low-Profile Antennas and Personal Communication Antennas</b>	<b>465</b>		
11.1 Introduction	465		
11.2 Microstrip Antenna Elements	466		
11.2.1 Rectangular Microstrip Patch Antennas	468		
11.2.2 Other Microstrip Patch Antennas and Their Applications	475		
11.2.3 Broadband Microstrip Patch Antennas	477		
11.3 Microstrip Arrays	478		
11.4 Microstrip Leaky Wave Antennas	481		
11.4.1 Characteristics of Leaky Wave Antennas	481		
11.4.2 Microstrip Modes	483		
11.4.3 Propagation Regimes	485		
11.5 Fundamental Limits on Antenna Size	488		
11.5.1 The Fundamental Limit on Antenna Size	490		
11.5.2 Practical Aspects of Antenna Size Limits	492		
11.5.3 Antenna Loading and Impedance Matching	496		
11.6 Antennas for Compact Devices	498		
11.6.1 Normal Mode Helix Type Antennas	499		
11.6.2 Quadrifilar Antennas	501		
11.6.3 Planar Inverted-F Type Antennas	502		
11.6.4 Other Compact Antennas, Including Multiband/Broadband Handset Antennas	506		
11.6.5 Radio Frequency Identification (RFID) Antennas	508		
11.7 Dielectric Resonator Antennas	512		
11.8 Near Fields of Electrically Large Antennas	519		
11.8.1 Near Field of a Uniform Rectangular Aperture	519		
11.8.2 Calculating Near Fields	520		
11.9 Human Body Effects on Antenna Performance	523		
11.10 Radiation Hazards	526		
References	531		
Problems	533		
<b>Chapter 12 • Terminal and Base Station Antennas for Wireless Applications</b>	<b>536</b>		
12.1 Satellite Terminal Antennas	537		
12.2 Base Station Antennas	538		
12.3 Mobile Terminal Antennas	545		
12.4 Smart Antennas	549		
12.5 Adaptive and Spatial Filtering Antennas	553		
12.5.1 Switched Beam Antenna Systems	553		
12.5.2 Adaptive Antennas in General	554		
12.5.3 Van Atta Retrodirective Array	554		
12.5.4 Adaptive Receiving Arrays	555		
References	557		
Problems	557		

**Chapter 13 • Antenna Measurements**

13.1 Reciprocity and Antenna Measurements	559
13.2 Pattern Measurement and Antenna Ranges	564
13.3 Gain Measurement	571
13.3.1 Gain Measurement of Linearly Polarized Antennas	572
13.3.2 Gain Measurement of Circularly Polarized Antennas	573
13.3.3 Radiation Efficiency Measurement	575
13.3.4 Gain Measurement of Large Antennas	575
13.3.5 Summary of Gain Determination Methods	576
13.4 Polarization Measurement	576
13.4.1 The Polarization Pattern Method	577
13.4.2 The Spinning Linear Method	578
13.4.3 The Dual-Linear Pattern Method	578
13.5 Field Intensity Measurement	580
13.6 Mobile Radio Antenna Measurements	582
13.7 Rules for Experimental Investigations	583
References	584
Problems	584

**Chapter 14 • CEM for Antennas: The Method of Moments**

14.1 General Introduction to CEM	587
14.2 Introduction to the Method of Moments	587
14.3 Pocklington's Integral Equation	590
14.4 Integral Equations and Kirchhoff's Network Equations	591
14.5 Source Modeling	594
14.6 Weighted Residuals and the Method of Moments	596
14.7 Two Alternative Approaches to the Method of Moments	601
14.7.1 Reaction	606
14.7.2 Linear Algebra Formulation of MoM	606
14.8 Formulation and Computational Considerations	607
14.8.1 Other Expansion and Weighting Functions	610
14.8.2 Other Electric Field Integral Equations for Wires	610
14.8.3 Computer Time Considerations	612
14.8.4 Toeplitz Matrices	614
14.8.5 Block Toeplitz Matrices	616
14.8.6 Compressed Matrices	616
14.8.7 Validation	617
14.9 Calculation of Antenna and Scatterer Characteristics	618
14.10 The Wire Antenna or Scatterer as an <i>N</i> -Port Network	618
14.10.1 Series Connections	621
14.10.2 Parallel Connections	621
14.11 Antenna Arrays	622
14.11.1 The Linear Array	625
14.11.2 The Circular Array	626
14.11.3 Two-Dimensional Planar Array of Dipoles	629
14.11.4 Summary	630
14.12 Radar Cross Section of Antennas	631
14.13 Modeling of Solid Surfaces	636
14.13.1 Wire-Grid Model	637
14.13.2 Continuous Surface Model	641
14.14 Summary	645
References	646
Problems	647

**559**

559
564
571
572
573
575
575
576
576
577
578
578
580
582
583
584
584

**Chapter 15 • CEM for Antennas: Finite Difference Time Domain Method**

15.1 Maxwell's Equations for the FDTD Method	652
15.1.1 Three-Dimensional Formulation	654
15.1.2 Two-Dimensional Formulation	655
15.1.3 One-Dimensional Formulation	656
15.2 Finite Differences and the Yee Algorithm	657
15.3 Cell Size, Numerical Stability, and Dispersion	664
15.4 Computer Algorithm and FDTD Implementation	667
15.5 Absorbing Boundary Conditions	670
15.6 Source Conditions	674
15.6.1 Source Functionality	674
15.6.2 The Hard Source	675
15.6.3 The Soft Source	676
15.6.4 Total-Field/Scattered-Field Formulation	676
15.6.5 Pure Scattered-Field Formulation	680
15.7 Near Fields and Far Fields	681
15.8 A Two-Dimensional Example: An <i>E</i> -Plane Sectoral Horn Antenna	682
15.9 Antenna Analysis and Applications	689
15.9.1 Impedance, Efficiency, and Gain	689
15.9.2 The Monopole over a PEC Ground Plane	690
15.9.3 Microstrip Leaky Wave Antennas	695
15.10 Summary	697
References	697
Problems	698

**587**

587
590
591
594
596
601
606
606
607
610
610
612
614
616
616
617
618
618
621
621
622
625
625
626
629
630
631
636
637
641
645
646
647

**Chapter 16 • CEM for Antennas: High-Frequency Methods**

16.1 Geometrical Optics	700
16.2 Wedge Diffraction Theory	701
16.3 The Ray-Fixed Coordinate System	707
16.4 A Uniform Theory of Wedge Diffraction	716
16.5 <i>E</i> -Plane Analysis of Horn Antennas	718
16.6 Cylindrical Parabolic Reflector Antennas	722
16.7 Radiation by a Slot on a Finite Ground Plane	725
16.8 Radiation by a Monopole on a Finite Ground Plane	727
16.9 Equivalent Current Concepts	730
16.10 A Multiple Diffraction Formulation	732
16.11 Diffraction by Curved Surfaces	735
16.12 Application of UTD to Wireless Mobile Propagation	737
16.13 Extension of Moment Method Using the UTD	742
16.14 Physical Optics	745
16.15 Frequency Dependence of First-Order Scattering Sources	750
16.16 Method of Stationary Phase	757
16.17 Physical Theory of Diffraction	760
16.18 Cylindrical Parabolic Reflector Antennas—PTD	763
16.19 Summary	769
References	771
Problems	771
	773

**Appendix A • Frequency Bands**

A.1 Radio Frequency Bands	781
A.2 Television Channel Frequencies (in North America)	781
A.3 Cellular Telephone Bands	782
A.4 Radar Bands	782

**652**

652
654
655
656
657
664
667
670
674
675
676
676
680
681
682
689
690
695
697
697
698

**700**

700
701
707
716
718
722
725
727
730
732
735
737
742
745
750
757
760
763
769
771
771
773

**781**

781
781
782
782

<b>Appendix B • Material Data and Constants</b>	<b>783</b>
B.1 Conductivities of Good Conductors	783
B.2 Wire Data	783
B.3 Dielectric Constant: Permittivity of Free Space	784
B.4 Permeability of Free Space	784
B.5 Velocity of Light of Free Space	784
B.6 Intrinsic Impedance of Free Space	784
B.7 Properties of Some Common Dielectrics	784
<b>Appendix C • Coordinate Systems and Vectors</b>	<b>785</b>
C.1 The Coordinate Systems and Unit Vectors	785
C.2 Vector Identities	786
C.3 Vector Differential Operators	787
<b>Appendix D • Trigonometric Relations</b>	<b>789</b>
<b>Appendix E • Hyperbolic Relations</b>	<b>791</b>
<b>Appendix F • Mathematical Relations</b>	<b>793</b>
F.1 Dirac Delta Function	793
F.2 Binomial Theorem	793
F.3 Bessel Functions	793
F.4 Some Useful Integrals	794
<b>Appendix G • Computing Tools for Antennas</b>	<b>795</b>
G.1 Wire Antenna Simulation Packages	795
G.2 Parabolic Reflector Antenna Simulation Packages	796
G.3 Web Sites with Antenna Calculation and Modeling Tools	796
<b>Appendix H • Book List</b>	<b>797</b>
H.1 Introduction	797
H.2 Antenna Definitions	797
H.3 Fundamental Books on Antennas	797
H.4 Books on Antennas with Propagation	799
H.5 Books On Antennas With Other Topics	799
H.6 Handbooks and General Reference Books on Antennas	799
H.7 Books on Antenna Measurements	800
H.8 Books on Specific Antenna Topics	801
H.9 Books on Antennas For Specific Applications	805
H.10 Books on Computational Methods for Antennas	807
H.11 Books on Topics Closely Related to Antennas	809
<b>Index</b>	<b>811</b>